

## Materials Science and Technology Applied Polymer Science

# High-Char Foams for Abnormal Thermal Environmental Protection



Figure 1: A foam pillar transformed into a solid char with structural properties.

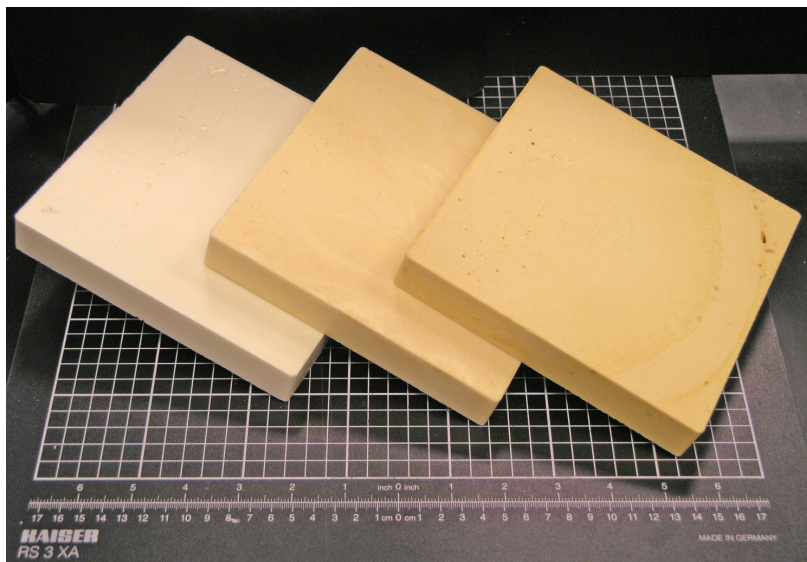


Figure 2: Examples of high char foam blocks ranging in density from 6 to 20 pounds per cubic foot.

*Sandia develops novel  
packaging foams with  
previously inaccessible  
performance characteristics*

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Many customized engineering systems developed at Sandia require sophisticated packaging to protect them from vibrational shock environments, thermal gradients, radiation exposures or particulate contamination. Systems requiring protection include sensitive electronic parts (microchips, electronic circuit boards), integrated satellites, and weapon system components. Packaging materials such as foams, conformal coatings, encapsulants and potting materials have one key feature in common - they involve the curing of reactive resins (their chemical building blocks), into a solid material with pre-defined properties. Thus, in many cases, the packaging materials share attributes no different than those found in common household epoxies, curable adhesives, or spray-on-demand foams.

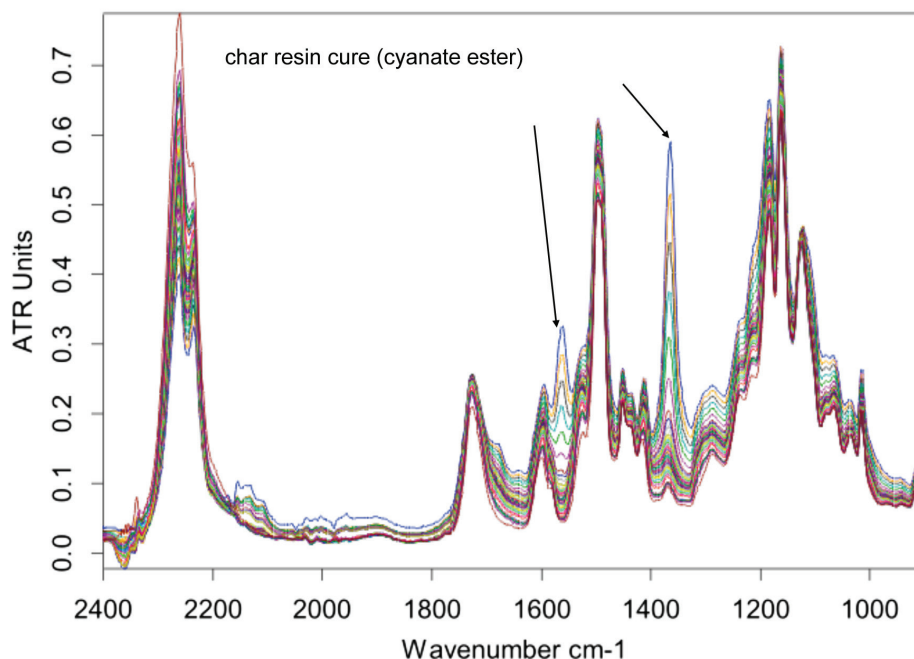
Nearly all of the commercially available resins that are precursors for foam materials are relatively sensitive

to pyrolytic decomposition at elevated temperatures, leading to mostly gaseous and liquid residues with minimal solid char formation. Thus exposure of packaged system components to abnormally high temperatures would result in unpredictable decomposition and poor solid, structural protection. With the ongoing emphasis in weapons engineering on surety innovation and predictable performance under abnormal environmental conditions, the high temperature behavior of encapsulation foams is a critical factor controlling the time-dependent behavior of thermal shielding and heat transfer. As long as a foam is capable of retaining its dimensions and shape by forming high amounts of solid black char residues (see Figure 1), then systems modeling is seen as a viable option to predict the condition of the protected internal components. Knowing precisely what thermal exposure may lead to is very important to better assess risk scenarios.

A Sandia research team has succeeded in developing a novel protective foam material that becomes 55% carbon char at 800°C (Figures 1 and 2). Unlike previously published materials, it does not rely on inorganic fillers that may introduce unwanted heavier elements or a higher viscosity that may lead to difficulties during foam processing. Instead, it is a hybrid material that uses a combination of an intrinsically high-char-forming cyanate ester resin (a customized resin precursor used in printed circuit boards and specialized composites), a high-char-yielding epoxy resin, a polymeric isocyanate resin for foaming and curing commonly used in polyurethane foams, and some additives for extra crosslinking and cure catalysis. There were several key steps in the development. These were recognizing the individual resin features, blending them into a synergistic material, understanding the competing cure reaction demands, and finally triggering specific cure kinetics with the help of suitable catalysts. In addition, the application of infrared spectroscopy (Figure 3) has enabled in-depth characterization of the cure reactions and resin interactions. The final product is a unique material that foams, solidifies and chars as required.

As with all reactive polymer foams, the foaming occurs in parallel with cure reactions. Liquid resins will transition into a solid material as the foam expands due to the significant exothermicity of the underlying crosslinking chemistry. Temperature control in the foam interior and reliable cure kinetics is absolutely critical to prevent overheating of larger foam blocks (Figure 2) and to establish a suitable framework for successful resin mixing and processing. A significant amount of work was devoted towards understanding individual reactions and mixing aspects of the foam system.

In terms of thermal expansion, glass transition temperature, and mechanical properties such as compression strength and modulus, the high char foam is as tough and attractive as other foams for structural and encapsulation purposes. Thus Sandia's first generation of this material is an excellent example of how applied polymer science can deliver a novel material for niche applications with previously inaccessible performance characteristics.



**Figure 3:** Time-dependent infrared spectroscopy provides information on the nature and timing of individual cure reactions (ATR = Attenuated total reflection). Cyanate ester reactions have specific spectral signatures and peak evolution (arrows) as a function of time.